Collisional Energy Loss in Semi-Quark Gluon Plasma†

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Quantum chromodynamics (QCD) above the deconfinement temperature T_c is in quark gluon plasma (QGP) phase. The QGP produced in the relativistic heavy ion collider (RHIC) and large hadron collider (LHC) remains in a temperature window $T_c \sim 2T_c$ for much of its lifetime. This is a regime where high-temperature perturbation theory becomes inappropriate. The regime is called semi-QGP, which is characterized by a non-trivial Polyakov loop. A matrix model with background color charges $A_0^{\rm cl} = i/g\,{\rm diag}(-Q,0,Q)$ has been proposed to describe the physics in the regime[1]. The background color charges can be viewed as imaginary chemical potentials for quarks and gluons, which effectively suppress their number density as compared to high-temperature QGP. In this letter, we considered how the suppression of quark and gluon number density affects heavy-quark collisional energy loss in semi-QGP.

It is known that heavy quarks lose their energy by Coulomb scattering and Compton scattering, in which heavy quarks scatter off gluons and a light quarks respectively. Both processes contribute to total energy loss. The presence of background color charges suppresses light quark and gluon number densities differently, resulting in different suppression factors for energy loss corresponding to the two processes. For Coulomb scattering, we found that the energy loss per unit length, to the leading logarithmic order, is given by a Q-dependent factor $S^{\rm qk}(Q)$ times the energy loss at $Q=0$:

$$\left.\frac{dE}{dx}\right|_Q^{\rm qk} = S^{\rm qk}(Q)\ \left.\frac{dE}{dx}\right|_{Q=0}^{\rm qk} . \tag{1}$$

The energy loss, to the leading logarithmic order, at $Q=0$ is as follows[2]:

$$\left.\frac{dE}{dx}\right|_{Q=0}^{\rm qk} = \frac{2}{9}\,\pi\,\alpha_s^2\,T^2\,N_f\ \ln\left(\frac{ET}{m_D^2}\right), \tag{2}$$

where N_f and $\alpha_{\rm s}$ are respectively the number of light quark flavors and strong coupling constant. m_D is the gluon Debye mass. $S^{\rm qk}(Q)$ is the infinite sum of traces of the Wilson loop $\mathbb{L} \equiv \mathcal{P}e^{ig\int_0^{1/T} d\tau A_0^{cl}}$:

$$S^{\rm qk}(Q) = \frac{4}{\pi^2}\sum_{n=1}^{\infty}\frac{(-)^{n+1}}{n^2}\,{\rm tr}\,\mathbb{L}^n\ . \tag{3}$$

The energy loss from Compton scattering also factorizes to a Q dependent factor and the energy loss at $Q=0$ to leading logarithmic order.

$$\left.\frac{dE}{dx}\right|_Q^{\rm gl} = S^{\rm gl}(Q)\ \left.\frac{dE}{dx}\right|_{Q=0}^{\rm gl} . \tag{4}$$

The energy loss at $Q=0$ can be expressed as follows[2]:

$$\left.\frac{dE}{dx}\right|_{Q=0}^{\rm gl} = \pi\,\alpha_s^2\,T^2\left(\frac{4}{3}\ln\left(\frac{ET}{m_D^2}\right)+\frac{8}{27}\ln\left(\frac{ET}{M^2}\right)\right), \tag{5}$$

where M is the mass of heavy quark. $S^{\rm gl}(Q)$ again involves an infinite sum of traces of the Wilson loop

$$S^{\rm gl}(Q) = \frac{1}{8}\left(\frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{|{\rm tr}\,\mathbb{L}^n|^2}{n^2}-1\right) . \tag{6}$$

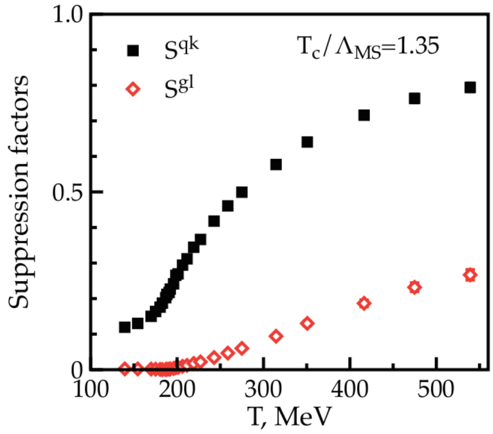

Fig. 1. Suppression factors for Coulomb scattering $S^{\rm qk}$ and Compton scattering $S^{\rm gl}$.

The suppression factors $S^{\rm qk}(Q)$ and $S^{\rm gl}(Q)$ are both functions of temperature through Q, whose temperature dependence is extracted from results of lattice simulation on Polyakov loop. Fig. 1 shows the plots of $S^{\rm qk}(Q)$ and $S^{\rm gl}(Q)$ versus T. We found that Coulomb scattering and Compton scattering are significant suppressed as QGP approaches T_c from temperature above T_c. It is also noteworthy that the suppression is much greater for Compton scattering than for Coulomb scattering.

References

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